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TCP Performance Enhancement for UMTS Access Network

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Abstract

We aim at optimize the TCP performance over UMTS access network challenged by the large delay bandwidth product that is mainly caused by the latency from the link layer ARQ retransmissions and diversity technique at physical layer. We propose to place a split TCP proxy at GGSN nodes which is between UMTS access network and Internet. The split proxy divides the bandwidth delay product into two parts, resulting in two TCP connections with smaller bandwidth delay products. Simulation results show, the split TCP proxy can significantly improve the TCP performance under high bit rate DCH channel scenario (e.g.256 kbps). Besides, the split TCP proxy brings more performance gain for downloading large files than downloading small ones. Finally, an aggressive initial TCP congestion window size at proxy can brings even more performance gain for radio links with high data rates DCH channels with large delay bandwidth product.

1. Introduction

Ubiquitous Internet access is regarded as a key success factor for third generation mobile communication system. WCDMA/UMTS [1, 2] shows this trend by providing efficient support for packet-switched data services with data rates up to 384 kb/s for wide area coverage and maximum 2M bits/s for hot spot areas. The mobile internet access over UMTS is expected to bring one or two order of magnitude higher data rates than the previous 2G cellular networks. However, it is important that the combination of Internet application and underlying transport layer can make good use of the underlying large network capacity provided by WCDMA air interface.

One of the main problems of UMTS network is TCP throughput degradation in the large delay bandwidth products (up to around 20k bytes). A number of studies can be found in the literature [3, 4, and 7] have shown TCP performs poorly over wireless links. However, those studies primarily either focuses on optimize TCP to cope with radio transmission errors [4] or the long propagation delay in satellite system [7]. In contrast, we target at the large delay bandwidth product problem in UMTS access network. The large delay bandwidth product is mainly caused by either the variable end-to-end delay due to link layer ARQ retransmissions or the enhanced physical layer transmission bandwidth (which can be up to 2M kbps in UMTS and 10M kbps in High Speed Packet Access (HSPA)). The contributions of this work are two-folds: firstly, the TCP performance over UMTS dedicated transport channels (DCH) is studied under various delay bandwidth product scenarios. Unlike [5], our simulator incorporates the impact of packet loss rate of Internet. Secondly, a novel TCP split proxy concept is proposed to cope with the poor TCP performance under large delay bandwidth product scenarios. The split proxy is implemented at GGSN. With split proxy, a TCP connection from an Internet server is terminated in the proxy located at GGSN, and a second TCP connection is used towards the mobile client. The split proxy divides the bandwidth delay product into two parts, resulting in two TCP connections with smaller bandwidth delay products which can be pipelined and thus operating at higher speeds.

The rest of the paper is organized as follows. In section 2, we introduce the UMTS network architecture. In section 3, we present the concept of split TCP proxy.

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In section 4, we describe the simulation settings for evaluating TCP performance with and without split proxy. The simulation results and analysis are described in section 5. We draw final conclusions in section 6.

2. Overview of UMTS Network

a. WCDMA network architecture

Figure 1 shows the WCDMA network architecture in packet switch operation [6]. The network functionality is divided into three groups: User Equipment (UE), UMTS Terrestrial Radio Access Network (UTRAN) and Core Network (CN). UTRAN consists of Node B and Radio Network Controller (RNC). The CN comprises two basic nodes: Serving GPRS Support Node (SGSN) and Gateway GPRS support Node (GGSN). It acts as the backbone for the radio network and the connectivity toward external networks. GGSN provides inter-working with external packet-switched networks such as public internet or corporate intranets via the GI interface. SGSN is connected to RNC via the IuPS interface. SGSN is connected to RNC via the luPS interface. UE is connected to UTRAN over the WCDMA radio interface Uu.

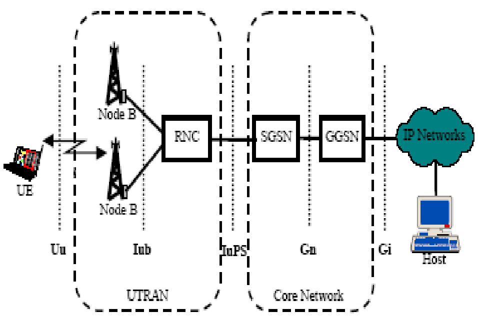

Figure 1: WCDMA network architecture in PS domain

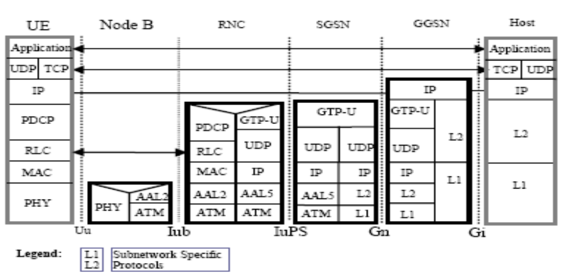

Figure 2: WCDMA protocol architecture-User-Plane. RLC provides reliable data transfer over error prone radio link by ARQ retransmission.

b. UMTS network protocol architecture

Figure 2 depicts the WCDMA protocol architecture for the transmission of user data plane data which is generated by TCP or UDP based applications. The applications as well as the TCP/IP protocol suite are located at the end-nodes: UE and host. Basically, WCDMA provides two types of channels: dedicated channels (DCH) exclusively used by one user and common channels shared between users. In this work, only DCH channels are considered.

Four different protocols are involved in the transmission over the air interface:

- Packet Data Convergence Protocol (PDCP)
- Radio Link Control protocol (RLC)
- Medium Access Control (MAC)
- Physical layer (PHY)

The PDCP provides header compression functionality which improves spectra efficiency for transmitting IP packets over the radio interface.

The RLC provides link layer ARQ functionality which is typically required for dealing with packet loss due to radio transmission errors. RLC can operate in three different modes: The acknowledged mode, unacknowledged mode and transparent mode. Due to the TCP performance is sensitive to packet loss due to transmission errors, it is nature to user RLC acknowledge mode for TCP traffics. The acknowledged mode provides reliable data transfer over the error-prone radio interface via ARQ protocol. In the unacknowledged mode, the data transfer over the radio interface is not error free but with no additional delay due to retransmission. The functionality of transparent mode is similar to unacknowledged mode but no protocol information is attached to the PDU. RLC protocol in WCDMA provides the means to optimize the protocol for delay or throughput, or a trade-off between them. Basically, the protocol uses a selective repeat request strategy, where the acknowledgements are triggered by either poll flags sent by the data sender or the detection of erroneous blocks at the receiver, or based on periodic events.

The Medium Access Control (MAC) layer provides a set of logical channels to RLC. Besides, the MAC layer is responsible for controlling the amount of data sent according to negotiated minimum and maximum data rates during the radio bearer setup. The instantaneous data rate is determined for every transmission time interval (TTI). The MAC layer requests the amount of data buffered at the RLC layer, which is ready for transmission. Based on available radio resources and the amount of data to transmit, the MAC layer submits the appropriate number of RLC blocks to the PHY layer. The Physical layer (PHY) contains besides all radio frequency functionalities, the signal processing including Rake receiver, channel estimation, power control FEC, interleaving, and rate match.

3. Split TCP Proxy for UMTS

Performance Enhancing Proxies are introduced when the performance suffers due to characteristics of a link or sub-networks [9]. An important subclass of PEPs are split connections proxies. This means a TCP connection from one end system is terminated at the proxy and another connection originate there. With TCP proxy, local acknowledgement in the proxy about the state of a TCP connection can be used to enhance the performance by shortcutting the transmission of ACKs or retransmissions. In the context of UMTS, the proxy is only used for shortcutting the transmission of ACKs, as RLC takes care of the retransmissions. The placement of TCP proxy in UMTS network is indicated in figure 3. In UMTS, a TCP connection from an Internet server is terminated in the proxy located in the CN, and a second TCP connection is used towards the mobile client. To cope with the large delay bandwidth of UMTS network, the split proxy divides the bandwidth delay product into two parts, resulting in two TCPs with smaller bandwidth delay products and thus operating at higher speeds. Unlike previous work [10] [11], the purpose of introducing a TCP proxy is to increase the throughput during TCP slow start, rather than the fast packet loss recovery due to radio transmission errors , as the link layer of UMTS are carefully designed for radio transmission errors.

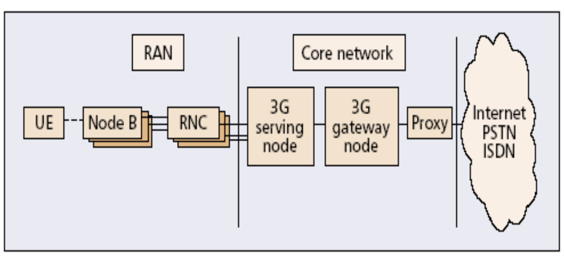

Figure 3: The Schematic of Split TCP Proxy in the end-to-end TCP path. The split TCP proxy is placed in between UMTS core network and Internet.

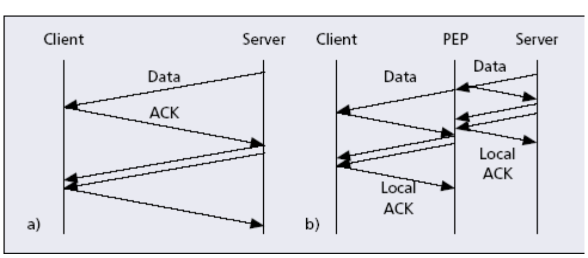

Figure 4: Schematic TCP transfer with and without Proxy. In the case of using split TCP proxy, by using the local ACK, two TCP connections can be pipelined for transmissions**.**

Figure 4 shows the difference in the information flow for the two cases with and without Split Proxy supporting local ACKs. While in case a, without Split Proxy the server has to wait for the response from the client resulting in a poor slow start performance, the Split Proxy speed up the data transfer in case b. The Split Proxy effectively implements pipelining for the two TCP connections. On the connections toward the client the PEP sends the first segment, and in parallel requests already new data from the server.

Secondly, to further enhance of UMTS radio link utilization, the TCP connection from proxy to client can be configured with an initial window size large than the two segment proposed by [12], or the three segment proposed by [13]. This approach is motivated by the observation: the RTT for the TCP connection traversing the Internet is typically smaller than the RTT for the connection over UMTS network. This means that during a conventional slow start, data arrive faster at the proxy than they can be sent toward the client when both two split TCP connections use the classic initial window size. To balance the speed of data transfer, a more aggressive TCP initial window over the radio bearer can enable the proxy forward more segments without waiting for ACKs from the client. Thus, during TCP slow start, the radio link can be more efficiently utilized since the TCP sending window can more quickly reach the maximum capacity of the radio link.

4. Simulation settings

We firstly evaluate the end-to-end TCP performance over WCDMA DCH channels without split proxy. Secondly, we compare the TCP performance with split proxy and without it. The performance evaluation is based on OPNET simulator [8]. This model assumes that an application transfers files on request from a server in the internet to a mobile client connect to

UMTS network. A TCP Reno is used as the transport protocol, which is configured for a mobile environment according to the recommendations in [14]. All radio protocols have been implemented in details as described earlier. The Internet and Core Network have been simplified by add a constant delay to transmit IP packets which is 100 ms for one way. In addition, independent packet losses are considered in the internet. For the radio link, it is assumed a dedicated physical channel is used. The power control is assumed to work perfectly, resulting in a constant block error rate on the radio link. Block errors are assumed to be independently distributed.

The RLC layer is configured in acknowledged mode and PDU delivery is in sequence. The RLC transmitting and receiving window is both 1024 PDUs while the SDU from upper layer is discard after MaxDAT times RLC layer retransmissions. Polling is not supported in OPENT model. The status report timer is 100 ms.

The TCP receiver advertised window (awnd) is 32768 Byte. The slow start threshold (ssthresh) is set to the size of awnd. The TCP retransmission timeout (RTO) is set to minimum 1 second and maximum 60 second. Fast retransmit is triggered after sender receives three duplicated ACKs from receiver.

The simulation parameters are given in the table 1:

As indicated in figure 3, the simulation setup is based on the system architecture discussed in the previous section. The network traffic is HTTP and FTP traffic, where the user behaviors of requesting files using HTTP and FTP are modeled such that the inter-request time follows exponential distribution with average value 30 seconds. The file size is in between 50, 100, or 200 Kbytes.

Table 1 Simulation Parameters

Parameter	Parameter	Description
Physical Layer	Transport Channel Type	DCH
	TTI	10 ms
	Channel Bite Rate	Constant=[64 128 256] kbps
	Closed Loop Power Control	Ideal (Independent erasures Block)
	Outer Loop Power Control	BLER Target=10%
RLC layer	Operation Mode	Acknowledged
	PDU Delivery	In-Sequence
	PDU Size	320 bits
	RLC_Tx Window Size	1024 PDUs
	RLC_Rx Window Size	1024 PDUs
	SDU Discard Mode	After MaxDAT
	MaxDAT	3, 5, 10
	Polling Mechamism	Not used
	Timer STATUS Periodic (milliseconds)	100
PDCP Layer	TCP/IP Header Compression	Header Fully Compress ed
TCP layer	Version	Reno
	MSS	536 B
	awnd	32768 B
	Initial cwnd	1,2,4 MSS
	Initial ssthresh	Awnd
	Initial RTO	3 sec
	Maximum RTO	60 sec
	Minimum RTO	1 sec
	Duplicated ACKs for fast retransmit	3
	Delay of internet and UMTS CN	100 ms (one way)
Application Layer	FTP	50,100 ,200 kb

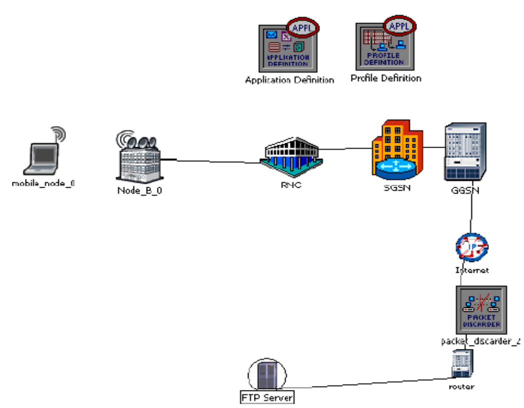

Figure 5: Simulation Setup

5. Simulation Results

From figure 10, the average RLC throughput is presented for different sizes of files being transmitted. It is clear that, for every small file sizes, very little performance gain can be achieved with a proxy. For a larger file size, a proxy gives significant performance gain. The major benefit of a proxy at rates of 64 and 128 kb/s is that it reduces the time spent in slow start. Since the proportion of slow start as part of the total transmission time decreases as the file sizes increases, the gain of TCP proxy increases. Besides, for a data rate of 256 kb/s, the gain increases further for larger file sizes. In this case, the link is underutilized not only during slow start, but also during fast retransmit and fast recovery after packet losses. For large files, fast retransmit and fast recovery becomes important. With proxy, the RLC throughput can significantly increase during fast retransmit and fast recovery after packet losses. To sum up, a proxy increase TCP performance for small data rates DCH mainly during the slow start, while for high data rates DCH both slow start phase and fast retransmit phase.

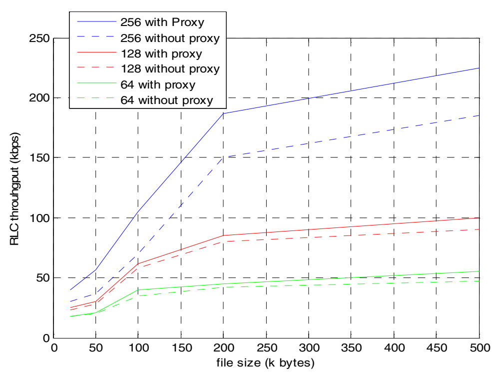

Figure 6: Average RLC throughput at different DCH rates for varying file sizes

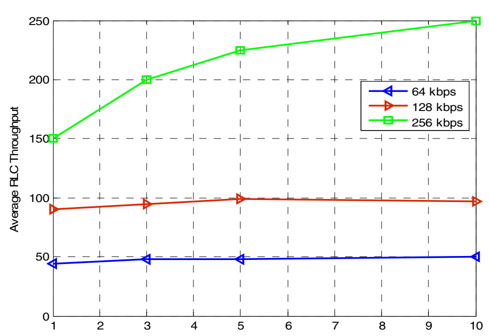

Figure7: Average RLC throughput at different DCH rates for different proxy configuration

Figure 11 compares, for different radio bearer rates, the average RLC throughput with and without proxy. For the proxy, different initial windows have been investigated. For a TCP configuration according to table 1, a proxy provides small gain for link rates of 64 and 128 kbps. Also, a large initial window of 10 segments in the proxy only marginally improves the results for these data rates. However, for the data rate of 256 kbps, a proxy with an initial window of 3 and 10 segments achieves the gain of 33% and 66% respectively. This shows that a aggressive initial TCP congestion window at proxy is particularly useful for radio links with high data rates whose delay bandwidth product is large.

6. Conclusion

To cope with large delay bandwidth product, we propose a split TCP proxy placed in between UMTS access network and Internet. By shortcutting the transmission of ACKs and pipelining for two split TCP connections, it can significantly improve the TCP performance under large delay bandwidth product scenarios. Simulation results show that: a split proxy increases TCP performance only during the slow start under low data rates DCH, while both slow start phase and fast retransmit phase under for high data rates DCH. Thus it brings more performance gain under high data rats DCH channels (thus high delay bandwidth product scenarios). Besides, the performance gain offered by proxy is larger for downloading large files than downloading small files. Finally, for the configuration of the split proxy, an aggressive initial TCP congestion window size (e.g. 10 MSS) at proxy is particularly useful for radio links with high data rates whose delay bandwidth product is large.

For a future work, we intend to analytically model the performance of TCP proxy over UMTS. One staring point is to develop an equation for the throughput of such a split connection as a function of packet loss rate, average round trip time, and the receiver's advertised window. The model can be built upon the model developed by Padhye et al [15].

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